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The major purpose of this experiment was to examine the effects of format (bar graphs vs. tables) and organization (by year vs. by brand) on the speed and accuracy of extrapolation and interpolation with multiple, nonlinear trend displays. Fifty-six undergraduates enrolled in the College of Education at the University of Delaware served as the data source. Subjects were assigned randomly to four format groups, varying in trend direction (increasing, decreasing) and acceleration (low, moderate, high). Interpolation was relatively fast and accurate and was unaffected by experimental variables. Extrapolated values were overestimated with decreasing trends and underestimated with increasing trends; this effect was greatest with highly accelerated trends. Response time was lower, but accuracy unaffected, when data were clustered so that trends were perceptually salient. The format and organization of visual displays of quantitative data should be investigated further, since both seem to play an important role in extrapolation performance. (Author/KS)

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The major purpose of this experiment was to examine the effects of format (bar graphs vs. tables) and organization (by year vs. by brand) on the speed and accuracy of extrapolation and interpolation with multiple, nonlinear trend displays. Fifty-six undergraduates enrolled in the College of Education at the University of Delaware served as the data source. Subjects were assigned randomly to four format groups, varying in trend direction (increasing, decreasing) and acceleration (low, moderate, high). Interpolation was relatively fast and accurate and was unaffected by experimental variables. Extrapolated values were overestimated with decreasing trends and underestimated with increasing trends; this effect was greatest with highly accelerated trends. Response time was lower, but accuracy unaffected, when data were clustered so that trends were perceptually salient. The format and organization of visual displays of quantitative data should be investigated further, since both seem to play an important role in extrapolation performance. (Author/KS)

The Effect of Format and Organization on Extrapolation and Interpolation with Multiple Trend Displays

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University of Delaware

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The Effect of Format and Organization on Extrapolation and Interpolation with Multiple Trend Displays

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Fifty-six undergraduates participated in an investigation of the effects of format (bar graphs vs. tables) and organization of data on the speed and accuracy of extrapolation and interpolation with multiple, nonlinear trend displays. Other variables of interest were trend direction (increasing, decreasing) and acceleration (low, moderate, high). Interpolation was relatively fast and accurate and was unaffected by experimental variables. Extrapolated values were overestimated with decreasing trends and underestimated with increasing trends; this effect was greatest with highly accelerated trends. Response latencies were lower, but accuracy was unaffected, when data were clustered so that trends were perceptually salient.

Objectives

It is widely believed that graphs and tables are effective media for displaying quantitative information. Evidence of this belief can be found by examining textbooks, scientific and technical journals, business reports and similar documents. Instructional programs in such diverse fields as geography, business and economics, mathematics, and the physical, biological and social sciences typically include the development of skill in the use and construction of graphs and tables as a major objective. In addition, examination of numerous standardized tests of educational achievement suggest that comprehension of information displayed in graphs and tables is a valued ability.

Two tasks for which graphical and tabular displays seem particularly well-suited are interpolation (e.g., in the use of tables of logarithms or cumulative distribution functions) and extrapolation (e.g., in the prediction of trends). However, very little systematic research has apparently been conducted to determine (a) the specific skills needed to perform these tasks; (b) the instructional techniques which maximize the acquisition of these skills; and (c) the effects of selected variables, such as format, visual complexity, and organization of data, on the utility of graphs and tables for transmitting quantitative information.

Washburne (1927) examined the effect of selected graphical, tabular and verbal methods of presenting time-varying quantitative information on retention in junior high school students. The criterion test measured performance on three types of test items: (a) specific amount items, requiring recall of the price of a particular product at a given point in time; (b) static comparison items, calling for comparison of the prices of two or more products at the same point in time; and (c) dynamic comparison items, requiring the comparison of price trends over a specific time interval. Washburne's data suggest that performance on each item type is affected by the manner in which the information is displayed (prose, pictograph, or bar graph), the amount of information presented, and the logical organization of the information within the display. However, the results are somewhat equivocal because completion (recall) items were used to assess specific amount learning, while multiple-choice (recognition) items were used to measure static and dynamic comparison performance. Schutz (1961a) studied the effect of format (vertical bar, horizontal bar and line graph), amount of irrelevant data, and amount of missing data on the speed and accuracy of performance on a single-trend detection task. He concluded that line graphs were most effective and horizontal bar graphs least effective for displaying single trends, and that performance tended to deteriorate as the amounts of irrelevant and missing data increased. In a second experiment (1961b), concerned with methods of displaying multiple trends, Schutz found that multiple-line single-graph displays were superior to single-line multiple-graph displays for point comparison tasks. However, Schutz did not study the effect of the organization or grouping of data on performance with bar graphs--a potentially important factor when this format is used to display multiple trends within a single graph (e.g., the annual earnings for each of four corporations over a ten-year period). In addition, neither Washburne nor Schutz investigated the relative efficacy of graphs and tables for displaying trends.

Perspective/Theoretical Framework

Recent studies (e.g., Frase, 1969) have dealt with the problem of learning prose from matrix-structured passages, where the dimensions of the matrix are classes and qualitatively different attributes of these classes. The matrix cells contain attribute values associated with each of the classes. Information having this kind of structure can be organized in several ways; the two most often studied are organization by row and organization by column. Quantitative information like that usually displayed in tables and graphs often has a similar matrix structure. For instance, the classes may be commodities, such as different brands of cereal, while the attribute dimension may consist of a single quantitative variable, such as time. The cells of the matrix then contain values of some time-varying quantity, such as unit price. This information may be organized or clustered in two ways in a table or bar graph. The prices of different brands of cereal may be grouped together for each year in the display (organization by year) or the varying prices of the same brand during successive years may be grouped together so that the price trend for each brand is perceptually salient (organization by brand). It seems reasonable to predict that the two types of organization should differentially affect performance on both interpolation and extrapolation tasks.

The major purpose of the present experiment was to examine the effects of format (bar graphs vs. tables) and organization (by year vs. by brand) on the speed and accuracy of performance on interpolation and extrapolation tasks with multiple, non-linear trend displays. Other independent variables included in this study were trend direction (increasing and decreasing) and trend acceleration (low, moderate and high).

Methods

Two data matrices were prepared showing the prices in cents per bar for each of three different brands of candy during each of the years 1930, 1940, 1950, 1960 and 1970. In one matrix, the price trends were increasing; in the other, trends were decreasing. For the first brand, differences between successive prices were 1, 2, 3 and 4. (For example, in the increasing trend condition, prices were 15, 16, 18, 21 and 25; in the decreasing trend condition, prices were 27, 26, 24, 21 and 17). For the second and third brands, differences between successive prices were 1, 3, 5, 7 and 1, 4, 7, 11, respectively. Thus, for each brand, the increasing and decreasing trends were determined by a "rule" (a regular sequence of successive price differences). The third trend showed the greatest acceleration (where acceleration was positive for the increasing trend, negative for the decreasing trend). The first trend showed the least acceleration.

For each of these data matrices, four stimulus displays were prepared, one for each of the format x organization conditions. The first display consisted of a table with the prices grouped by brand;

the second consisted of a table with the prices grouped by year. The third and fourth displays were vertical bar graphs with the prices grouped by brand and by year, respectively. The tables were typed on 8½" x 11" sheets of white paper, while the graphs were drawn on 8½" by 14" sheets of white paper. Subjects, who were tested individually, were randomly assigned in equal numbers to the four format x organization conditions. Each subject was instructed to estimate, to the nearest whole number, the price of each brand of candy in 1980 and in 1990 (extrapolation) as well as in 1945 and 1965 (interpolation), using both the increasing and decreasing trend displays. Subjects were told to work as quickly and as accurately as possible. The 24 extrapolation and interpolation questions were independently randomized for each subject, each of whom recorded his or her responses in a test booklet. Response latencies were recorded to the nearest hundredth of a second by the experimenter. Separate analyses of variance were performed on signed error scores and on log latencies.

<u>Data Source</u>

Fifty-six undergraduates enrolled in the College of Education at the University of Delaware served as volunteers. They were awarded credit toward course requirements for participation in the experiment.

<u>Results and Conclusions</u>

Error scores were computed by subtracting the correct extrapolated or interpolated value (determined by applying the rule for generating each trend) from each subject's response (see Table 1 for cell means and standard deviations). Analysis of variance of the error scores, using the Geisser-Greenhouse (1958) test with conservative degrees of freedom, showed significant main effects of trend direction ($F = 110.10$, $df = 1,52$; $p < .01$) and type of task ($F = 8.18$, $df = 1,52$; $p < .01$). Significant interactions were found between trend and task ($F = 137.50$, $df = 1,52$; $p < .01$), between trend and rule ($F = 78.81$, $df = 1,52$; $p < .01$), and between trend, task, and rule ($F = 42.33$, $df = 1,52$; $p < .01$). There was a consistent tendency to overestimate extrapolated prices when the trend was decreasing, and to underestimate them when the trend was increasing. When extrapolation was performed with the decreasing trends, 69.1% of the responses were overestimated, 11.6% were underestimated, and 19.3% were correct. With the increasing trend, 67.0% of the responses were underestimated, 12.2% were overestimated, and 20.8% were correct. The extrapolation error was greatest, for each trend direction, when the acceleration was greatest. The latter effect was most pronounced when trends were extrapolated to 1990, where mean errors were -13.3 and 15.6 for increasing and decreasing trends, respectively. In contrast, interpolated estimates were relatively accurate regardless of trend direction or acceleration; the largest mean error was only 1.30.

Analysis of variance of log latencies, again using conservative degrees of freedom, showed significant main effects of organization ($F = 8.866$, $df = 1,52$; $p < .01$), task ($F = 33.395$, $df = 1,52$; $p < .01$) and rule ($F = 36.294$, $df = 1,52$; $p < .01$) (see Table 2 for cell means and standard deviations). Significant interactions were found between format and trend ($F = 4.203$, $df = 1,52$; $p < .05$), between format and rule ($F = 4.786$, $df = 1,52$; $p < .05$) and between trend and rule ($F = 7.465$, $df = 1,52$; $p < .01$). Organization by brand appeared to enable subjects to search both tabular and graphical displays more rapidly than organization by year. In addition, interpolation was performed more quickly than extrapolation, with extrapolation to 1990 resulting in the longest latency. Response times were longest for trends with the greatest acceleration; this effect was most pronounced with increasing trends. Although there was no main effect of format on response latency, decreasing trends resulted in longer latencies for subjects viewing tabular displays. Moreover, the effect of trend acceleration appeared to be greater with tables than with graphs.

The results suggest that the hypothesized facilitating effect of organization by brand may be manifested in response latency rather than in accuracy; that is, subjects may be able to attain the same precision in less time when the data are clustered in such a way that the trends are readily perceived. The often-assumed superiority of graphs over tables for displaying trends was not supported by the results of the present experiment, perhaps because the rules for generating the trends were equally apparent with either the tabular or the graphical format.

The tendency to over- or underestimate in extrapolation, depending on the direction of the trend, was altogether consistent (see Figure 1). One possible explanation of this tendency is that it may have been an artifact of the way in which the graphical displays were constructed. In the case of the increasing trend with the greatest curvature, the correct value extrapolated to 1990 was 73, while the highest value on the vertical axis was only 70. That is, subjects may have perceived the value of 73 to be off the scale, and lowered their estimates accordingly. However, when one observes that this source of bias would not have been present with the tabular displays, or with the decreasing trend graphs, this explanation loses much of its plausibility.

Another, more reasonable interpretation is the following. Spencer (1961) found that subjects in a graphical extrapolation task tended to respond as though a regression line were to be constructed through the set of points in the stimulus. If the best-fitting straight line is constructed through a set of points which define an increasing function whose graph is concave upward, that line will underestimate extrapolation of the trend. Moreover, the underestimation will be greater for long-term than for short-term predictions, and will increase with increasing curvature of the trend. A similar argument shows that a regression line will lead to overestimation with a decreasing, concave-downward trend. Perhaps subjects in the present experiment resorted to a similar strategy, particularly when the acceleration of the trend, and distance between the last data point and the point to which extrapolation was to be made, combined to make application of the rule particularly difficult. The comparative efficiency with which interpolation was performed was reflected in both error and latency scores, and is not surprising. The task essentially involves locating the midpoint of a line segment joining two adjacent points in the Cartesian plane, and is both visually and computationally much easier than extrapolation.

Educational or Scientific Importance of the Study

The recent interest in the acquisition and retention of information from prose suggests that when the information is quantitative, factors influencing the effectiveness of accompanying tables and graphs should be given careful attention. The present experiment focused on selected, readily-manipulated characteristics of graphs and tables themselves, apart from related textual material. In view of the exploratory nature of the study, definite recommendations regarding the construction, selection or use of graphs and tables for instructional purposes seems premature. However, the results suggest that format and, particularly, organization should be investigated further, since both seem to play an important role in extrapolation performance, especially when the trends depart markedly from linearity. Identification of those factors which affect the acquisition and retention of information from graphs and tables will facilitate study of the usefulness of such displays as adjuncts in learning from prose, and in development of instructional strategies relevant to the acquisition of quantitative information from printed media.

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TABLE 1. SIGNED ERRORS

		Increasing											
		Extrapolation						Interpolation					
		1980			1990			1945			1965		
		R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Bars by Year	$\bar{x}$	0.07	-2.21	-3.93	-0.29	-6.71	-14.36	1.00	0.43	0.14	1.57	0.43	-1.21
	SD	4.86	2.04	3.97	6.09	3.50	7.89	3.57	4.48	2.93	4.07	1.34	2.94
Bars by Brand	$\bar{x}$	0.64	-0.79	-2.50	3.36	-4.93	-11.64	2.29	0.50	0.79	0.57	-0.14	-0.36
	SD	2.92	3.24	4.45	9.64	6.03	9.65	4.95	3.30	3.07	3.34	0.86	3.91
Tables by Year	$\bar{x}$	-0.14	0.64	-4.21	-3.43	-5.29	-12.93	0.00	0.64	0.07	-0.14	0.29	-1.21
	SD	0.53	5.47	3.95	5.72	4.63	7.52	0.00	0.50	0.27	1.03	2.20	3.53
Tables by Brand	$\bar{x}$	-1.00	-1.93	-2.00	0.43	-6.43	-14.14	0.14	-0.93	0.07	0.00	-0.07	-0.29
	SD	1.11	2.27	2.75	8.82	6.88	10.82	0.53	5.24	0.27	0.39	1.94	1.44

TABLE 1. SIGNED ERRORS (Continued)

		Decreasing											
		Extrapolation						Interpolation					
		1980			1990			1945			1965		
		R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Bars by Year	$\bar{x}$	1.93	2.29	2.86	4.93	12.43	13.64	-1.29	-0.43	-0.64	0.14	0.29	0.93
	SD	5.08	4.70	6.32	5.93	10.63	5.94	2.55	5.81	2.06	2.21	3.32	4.78
Bars by Brand	$\bar{x}$	0.21	2.43	1.86	1.93	6.71	16.00	-1.93	-1.00	-1.21	-0.86	-0.71	0.00
	SD	1.72	2.53	3.39	2.20	3.91	11.14	3.83	0.00	2.61	2.18	1.14	8.74
Tables by Year	x	0.93	2.57	2.71	3.43	11.21	18.36	-0.21	-0.07	0.00	0.31	-0.29	2.07
	SD	2.20	6.82	3.41	4.57	12.21	16.33	0.81	0.73	0.00	1.18	2.55	4.18
Tables by Brand	$\bar{x}$	0.64	3.07	2.86	3.57	11.57	14.21	-0.14	-1.29	0.36	-0.21	-2.00	2.21
	SD	1.78	4.76	4.66	7.07	13.15	10.43	0.53	4.38	1.08	0.58	7.23	5.29

TABLE 2. LOG LATENCIES

		Increasing											
		Extrapolation						Interpolation					
		1980			1990			1945			1965		
		R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Bars by Year	$\bar{x}$	2.62	2.87	2.66	2.72	2.86	2.65	2.56	2.77	2.75	2.57	2.93	2.88
	SD	0.55	0.58	0.50	0.60	0.47	0.67	0.38	0.57	0.44	0.50	0.45	0.58
Bars by Brand	$\bar{x}$	2.06	2.48	2.39	2.46	2.66	2.38	2.17	2.03	2.21	2.18	2.35	2.16
	SD	0.40	0.66	0.64	0.50	0.68	0.56	0.38	0.45	0.38	0.46	0.29	0.53
Tables by Year	$\bar{x}$	2.28	2.90	2.60	2.64	2.90	2.86	2.06	2.41	2.53	2.33	2.62	2.70
	SD	0.37	0.63	0.58	0.39	0.55	0.54	0.44	0.50	0.57	0.49	0.61	0.47
Tables by Brand	$\bar{x}$	2.22	2.38	2.35	2.40	2.66	2.50	2.01	2.21	2.41	2.10	2.51	2.41
	SD	0.41	0.62	0.61	0.40	0.69	0.65	0.36	0.43	0.47	0.40	0.63	0.33

TABLE 2. LOG LATENCIES

		Increasing											
		Extrapolation						Interpolation					
		1980			1990			1945			1965		
		R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Bars by Year	$\bar{x}$	2.62	2.87	2.66	2.72	2.86	2.65	2.56	2.77	2.75	2.57	2.93	2.88
	SD	0.55	0.58	0.50	0.60	0.47	0.67	0.38	0.57	0.44	0.50	0.45	0.58
Bars by Brand	$\bar{x}$	2.06	2.48	2.39	2.46	2.66	2.38	2.17	2.03	2.21	2.18	2.35	2.16
	SD	0.40	0.66	0.64	0.50	0.68	0.56	0.38	0.45	0.38	0.46	0.29	0.53
Tables by Year	$\bar{x}$	2.28	2.90	2.60	2.64	2.90	2.86	2.06	2.41	2.53	2.33	2.62	2.70
	SD	0.37	0.63	0.58	0.39	0.55	0.54	0.44	0.50	0.57	0.49	0.61	0.47
Tables by Brand	$\bar{x}$	2.22	2.38	2.35	2.40	2.66	2.50	2.01	2.21	2.41	2.10	2.51	2.41
	SD	0.41	0.62	0.61	0.40	0.69	0.65	0.36	0.43	0.47	0.40	0.63	0.33

TABLE 2. LOG LATENCIES (CONTINUED)

		Decreasing											
		Extrapolation						Interpolation					
		1980			1990			1945			1965		
		R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3
Bars by Year	$\bar{x}$	2.61	2.56	2.81	2.60	2.73	2.84	2.61	2.54	2.57	2.62	2.75	2.79
	SD	0.61	0.53	0.67	0.39	0.72	0.62	0.56	0.51	0.48	0.50	0.52	0.54
Bars by Brand	$\bar{x}$	2.27	2.37	2.31	2.37	2.66	2.43	2.14	2.18	2.08	2.14	2.32	2.23
	SD	0.58	0.50	0.51	0.62	0.62	0.68	0.40	0.37	0.49	0.53	0.57	0.46
Tables by Year	$\bar{x}$	2.70	2.78	2.87	2.78	3.06	2.82	2.33	2.25	2.54	2.63	2.58	2.78
	SD	0.38	0.78	0.53	0.61	0.55	0.45	0.27	0.37	0.29	0.36	0.44	0.48
Tables by Brand	$\bar{x}$	2.31	2.51	2.46	2.59	2.74	2.84	2.22	2.27	2.36	2.19	2.50	2.55
	SD	0.46	0.62	0.49	0.59	0.66	0.69	0.51	0.54	0.51	0.54	0.65	0.60

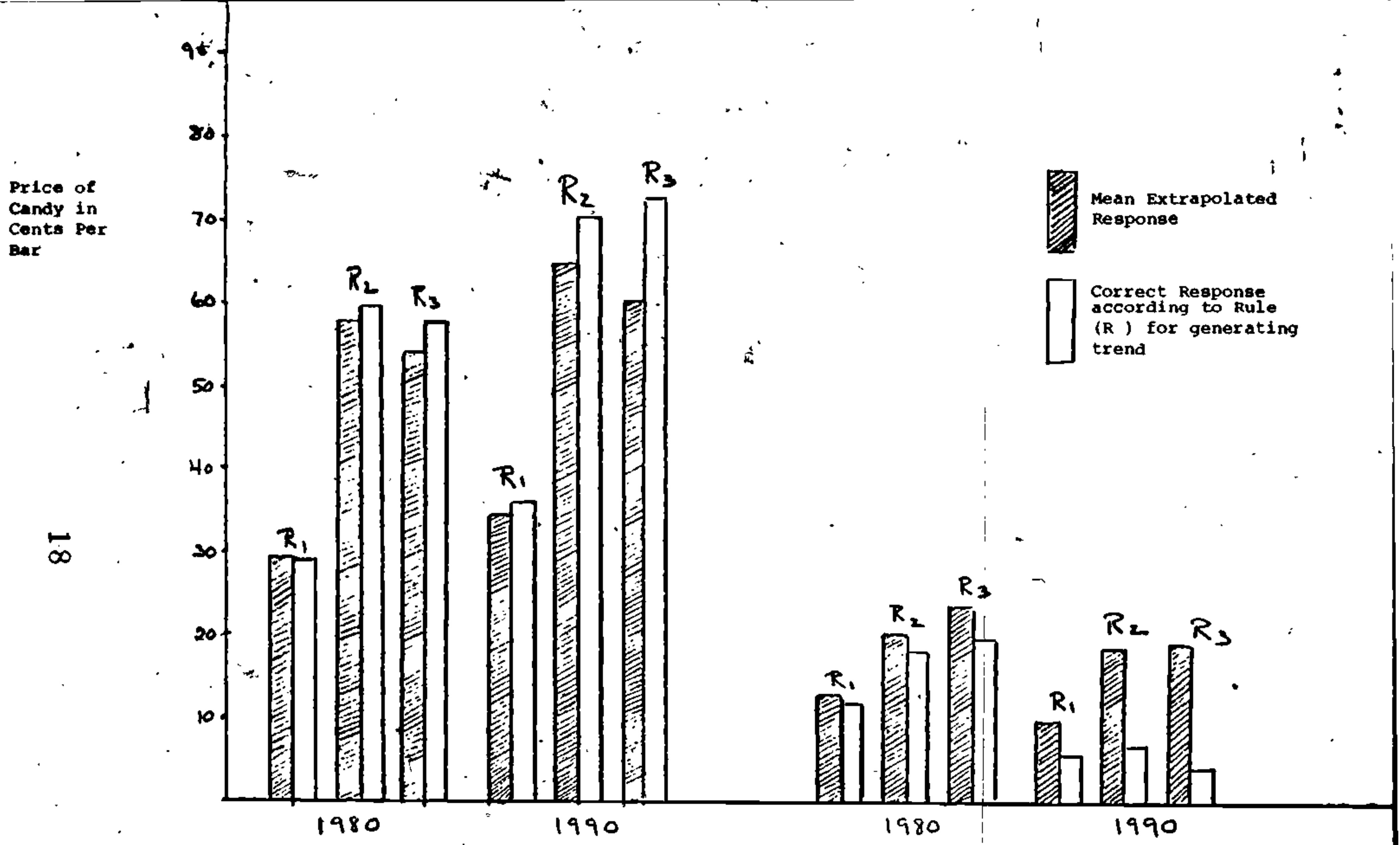

Fig. 1. Comparison of Mean Extrapolation Performance with Correct Extrapolated Response for Increasing and Decreasing Trends